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**APPLICATION
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HYPERBGA BUILDUP LAMINATE

Background of the Invention

1. Technical Field

The present invention relates to a method and structure for forming a redistribution structure on a circuitized substrate.

2. Related Art

Wireability within an electronic structure comprising a multilayered laminate is limited by physical dimensions of the multilayered laminate and physical structure within the multilayered laminate (e.g., through holes, blind vias, etc.). Accordingly, there is a need to increase wireability within an electronic structure comprising a multilayered laminate.

Summary of the Invention

The present invention provides an electronic structure, comprising:

an internally circuitized substrate having a metallic plane on a first surface of the substrate; and

15 a redistribution structure having N dielectric layers, N metal planes, and a microvia structure through the N dielectric layers, wherein N is at least 2, wherein dielectric layer 1 is on the first surface of the substrate and on the metallic plane, wherein metal plane J is on dielectric layer J for $J = 1, 2, \dots, N$, wherein dielectric layer I is on dielectric layer I-1 and on metal layer I-1 for $I = 2, \dots, N$, and wherein the microvia structure electrically couples metal plane N to the

metallic plane.

The present invention provides a method for forming an electronic structure, comprising:
providing an internally circuitized substrate having a metallic plane on a first surface of
the substrate; and

5 forming a redistribution structure including forming N dielectric layers, forming N metal
planes, and forming a microvia structure through the N dielectric layers such that the microvia
structure electrically couples metal plane N to the metallic plane, wherein N is at least 2, and
wherein forming the N dielectric layers and the N metal layers includes setting a dummy index
J=0 and looping over J as follows:

10 adding 1 to J;
if J = 1 then forming dielectric layer 1 on the first surface of the substrate and on
the metallic plane, else forming dielectric layer J on dielectric layer J-1 and on metal
plane J-1;
forming metal plane J on dielectric layer J; and
15 if J < N then returning to adding 1 to J and continuing the looping, else ending the
looping.

The present invention increase wireability within an electronic structure comprising a
multilayered laminate.

Brief Description of the Drawings

20 FIG. 1 depicts a front cross-sectional view of a substrate that includes a multilayered

laminate, in accordance with embodiments of the present invention.

FIG. 2 depicts FIG. 1 after two redistribution layers have been added to both top and bottom surfaces of the substrate.

FIG. 3 depicts FIG. 1 after three redistribution layers have been added to a top surface of
5 the substrate and after two redistribution layers have been added to a bottom surface of the
substrate.

Detailed Description of the Invention

FIG. 1 illustrates a front cross-sectional view of a substrate 10, in accordance with
embodiments of the present invention. The substrate 10 includes a multilayer laminate as shown,
including dielectric layers 12-17, a ground plane 20 between dielectric layers 14 and 15, a signal
plane 22 between dielectric layers 15 and 16, a power plane 24 between dielectric layers 16 and
17, a signal plane 21 between dielectric layers 13 and 14, and a power plane 23 between
dielectric layers 12 and 13. The substrate 10 also includes plated through holes (PTHs) 30-32
having through holes 34-36 and metallic plating (e.g., copper plating) 37-39, respectively.

15 Electrically conductive pads (e.g., copper pads) 40-42 on a top surface 48 of the substrate
10 are integral with (and thus electrically coupled with) the metallic platings 37-39 of the PTHs
30-32, respectively. Electrically conductive pads (e.g., copper pads) 43-45 on a bottom surface
49 of the substrate 10 are integral with (and thus electrically coupled with) metallic platings 37-
39 of the PTHs 30-32, respectively. A signal plane 51 having electrically conductive regions 46
20 comprising an electrically conductive metal such as, *inter alia*, copper is on the top surface 48 of

the substrate 10. A signal plane 52 having electrically conductive regions 47 comprising an electrically conductive metal such as, *inter alia*, copper is on the bottom surface 49 of the substrate 10. The electrically conductive regions 46 and 47 may include, *inter alia*, electrically conductive lines or electrically conductive pads.

5 The dielectric layers 12-17 each include a dielectric material 18 such as a polytetrafluoroethylene (PTFE) material filled with silicon particles, or other dielectric materials as are known in the art for use with multilayer chip carriers (e.g., such epoxy resins, polyimide, polyphenylene ethers, etc.). The ground plane 20 includes a conductive metal such as, *inter alia*, a copper-INVAR®-copper (CIC) layered structure, at a common voltage level. The signal planes 21 and 22 each include conductive lines 26 and 28, respectively, comprising an electrically conductive metal such as, *inter alia*, copper. The power planes 23 and 24 each include electrically conductive metal (e.g., copper) at a common voltage level that differs from, and is higher than, the common voltage level of the ground planes 20. The power planes 23 and 24 include more metal and are stiffer than the signal planes 21 and 22 and, accordingly, help to protect the signal planes 21 and 22 from being damaged by thermally induced stresses such as during thermal cycling or during any other thermal transient operation.

10 The substrate 10 in FIG. 1 may be formed by first laminating dielectric layers 14 and 15 to opposite surfaces of the power plane 20, followed by forming the signal planes 21 and 22 on the dielectric layers 14 and 15, respectively. Dielectric layers 13 and 16 are formed on the signal planes 21 and 22, respectively. Power planes 23 and 24 are formed on the dielectric layers 13 and 16, respectively. Dielectric layers 12 and 17 are formed on the power planes 23 and 24,

respectively. At this stage of the formation of the substrate **10**, the dielectric material **18** is continuously distributed within the substrate **10**.

Next, through holes **34-36** are formed through the substrate **10** by any method known to one of ordinary skill in the art such as by, *inter alia*, laser drilling. Debris is cleaned from surfaces of the holes using known cleaning techniques. The through holes **34-36**, the top surface **48**, and the bottom surface **49**, are plated with an electrically conductive metal (e.g., copper) by any method known to one of ordinary skill in the art (e.g., electroless plating of copper followed by acid electroplating of copper), resulting in formation of platings **37-39** on walls of the through holes **34-36**, respectively. The conductive pads **40-42** and the conductive regions **46** are formed by applying selective etching techniques with photolithography (or using other applicable techniques known to one of ordinary skill in the art) to the plating or foil (e.g., copper plating or copper foil) on the top surface **48**. Similarly, the conductive pads **43-45** and the conductive regions **47** are formed by applying selective etching techniques with photolithography (or using other applicable techniques known to one of ordinary skill in the art) to the plating or foil (e.g., copper plating or copper foil) on the bottom surface **49**. The resultant conductive metal of the signal planes **51** and **52** may comprise chlorited copper (i.e., copper that has been treated with chlorite to produce a roughened surface) for enhancing an adhesion strength of redistribution layers which will be subsequently formed on the signal planes **51** and **52** (as discussed *infra* in conjunction with FIGS. 2 and 3).

In FIG. 1, the number and distribution of ground planes, signal planes, power planes, and PTHs comprised by the substrate **10** is merely illustrative. It is within the scope of the present

invention for the substrate **10** to include any number and distribution of ground planes, signal planes, power planes, and PTHs, as required in any given application and as compatible with dimensions of the substrate **10**. Also, a PTH may be replaced by a plated buried via or a plated blind. In addition, the signal planes **51** and **52** on the top surface **48** and bottom surface and **49**, respectively, may each be replaced by any surface distribution of conductive metal such as, *inter alia*, a power plane or a ground plane.

Definitionaly, the substrate **10** includes all structure shown in FIG. 1. Also definitionaly, the top surfaces **48** and **49** of the substrate **10** include the exposed surfaces of the dielectric layers **12** and **17**, respectively, but do not include exposed surfaces of the conductive pads **40-42**, the conductive pads **43-45**, and the conductive regions **46-47**.

FIG. 2 illustrates FIG. 1 after a two-layer redistribution structure has been added to both the top surface **48** and the bottom surface **49** of the substrate **10**, in accordance with embodiments of the present invention. In particular, FIG. 2 illustrates an electronic structure **100**, comprising: the substrate **10**, a redistribution layer **60** on the top surface **48** of the substrate **10**, a redistribution layer **70** on the redistribution layer **60**, a redistribution layer **80** on the bottom surface **49** of the substrate **10**, and a redistribution layer **90** on the redistribution layer **80**.

The electronic structure **100** also includes an electronic device (e.g., a semiconductor chip) **110** coupled to the redistribution layer **70** by solder members **120-122** (e.g., Controlled Collapse Chip Connection, or “C4”, solder balls), wherein conductive pads **127- 129** conductively interface the solder members **120-122** to the electronic device **110**. Additionally, the electronic structure **100** includes an electronic card or board (e.g., circuit card) **115** solderably

coupled to the redistribution layer 90 by solder members 124 and 125 (e.g., ball grid array, or "BGA", solder balls), wherein conductive pads 116 and 117 conductively interface the solder members 124 and 125 to the electronic card or board 115. An underfill material (e.g., an organic resin or any underfill material known in the art) 130 encapsulates the solder members 120-122 and fills a space between the electronic device 110 and the redistribution layer 70. The underfill material 130 mitigates adverse effects on the structural integrity of the solder members 120-122 caused (during thermal cycling or other thermal transients) by a mismatch in coefficient of thermal expansion (CTE) between the electronic device 110 and the electronic card or board 115, and/or between the electronic device 110 and the solder members 120-122.

The electronic structure 100 is formed as follows. Starting with the substrate 10 of FIG. 1, redistribution layers 60 and 80 are laminated over the top surface 48 and the bottom surface 49 of the substrate 10, respectively, covering the conductive pads 40-42 and the conductive pads 43-45, respectively, as well as the conductive regions 46 and 47, respectively. Material of redistribution layers 60 and 80 also fill the PTHs 30-32. The redistribution layers 60 and 80 each include a dielectric material, such as DYNAVIA 2000TM (Shipley Ronal), polyimide, PSR-4000TM (from Taiyo Ink Co. Ltd.), VIALUX[®] (E. I. du Pont de Nemours and Company), and other similar materials made by Arlon, Asahi Chemical, and other similar companies. Such material must be capable of being reliably plated with conductive material such as copper after being laser drilled. For said plating on such material to be formable, and reliable during thermal cycling and circuit card-attach operations, such material is should, for embodiments described herein, be laser drillable, be copper platable, have a high thermal resistance or equivalently have

a high glass transition temperature (e.g., above about 150 °C), and have a low CTE (e.g., less than about 50 ppm/°C). Additionally, such material should have a high stiffness (e.g., at least about 700,000 psi) in order to protect conductive lines of signal planes on redistribution layers, as will be discussed *infra*.

5 After the redistribution layers **60** and **80** are formed, microvias **132** and **133** are formed in the redistribution layer **60** on the conductive pads **41** and **42**, respectively, and microvias **134** and **135** are formed in the redistribution layer **80** on the conductive region **47** and the conductive pad **45**, respectively. The microvias **132-135**, which are blind vias, are formed by any method known to one of ordinary skill in the art, such by, *inter alia*, laser drilling of holes, followed by cleaning debris from surfaces of the holes using known cleaning techniques, and plating an electrically conductive metal on the surfaces of the holes as known in the art (e.g., electroless plating of copper followed by acid electroplating of copper). The microvias **132** and **133** are electrically coupled to the PTHs **31** and **32**, respectively, and may therefore communicate electrically with internal layers of the substrate **10** as well as with the redistribution layer **80**. Since the microvia **135** is likewise electrically coupled to the PTH **32**, the microvias **133** and **135** are thus electrically coupled to each other. The microvia **134** is electrically coupled to the conductive region **47** of signal plane **52**, and is thus electrically coupled to any conductive structure in the signal plane **52** that the conductive region **47** is electrically coupled to. Exterior portions of the conductive platings on the microvias **132-133** extend outside of the microvias **132-133** and on exposed surfaces of the redistribution layers **60** and **80**, respectively. Such exterior portions of the conductive platings on the microvias **132-133** may thus serve as electrically conductive pads

or conductive wiring to which other conductive structure may be coupled. For example, such an exterior portion 131 of the conductive plating on the microvia 132 serves as a conductive region or conductive pad to which a conductively plated bottom portion of a microvia 145 is electrically coupled. Formation of the microvia 145 will be described *infra*.

5 Metal planes 140 and 141 are formed on the redistribution layers 60 and 80, respectively. The metal plane 140 includes conductive regions 137 and the conductive regions or pads 131 and 136. The metal plane 141 includes conductive regions 138 and the conductive region or pad 139. Generally, a "metal plane" is planar distribution of conductive metal at a level (i.e., at a distance from the top surface 48 or the bottom surface 49 of the substrate 10), wherein "planar" does not relate to a mathematical plane but rather to a plane of small but finite thickness. A metal plane may include, *inter alia*, a signal plane, a power plane, a ground plane, etc, as well as conductive pads or region which are integral with a microvia. A metal plane may be alternatively referred to as a "metallic plane."

10 Redistribution layer 70 is laminated over the redistribution layer 60 and over the metal plane 140, and redistribution layer 90 is laminated over the redistribution layer 80 and over the metal plane 141. Dielectric material of redistribution layer 70 fills the microvias 132 and 133, and dielectric material of redistribution layer 90 fills the microvias 134 and 135. The dielectric material of redistribution layers 70 and 90 of FIG. 3 is of the same type as the dielectric material of the redistribution layers 60 and 80.

15 Microvia 145 is formed in the redistribution layer 70 on conductive region 137 and conductive plating 131, and microvia 146 is formed in the redistribution layer 70 on conductive

region 137. Microvias 147 and 148 are similarly formed in the redistribution layer 90.

Additionally, microvia 144 is formed straight through the redistribution layers 70 and 60, and is thus directly coupled electrically to the PTH 30. The redistribution layers 70 and 90 are formed, and comprise material, as described *supra* in conjunction with the redistribution layers 60 and 5 80.

Metal planes 150 and 151 are formed on the redistribution layers 70 and 90, respectively. The metallic planes 150 and 151 include conductive regions 152 and 153, respectively, such as, *inter alia*, signal planes, power planes, ground planes, etc, as conductive pads and regions located at the level of the metallic planes 150 and 151.

10 The solder members 120-122 electrically couple the electronic device 110 to the microvias 144-146, respectively. The solder members 124-125 electrically couple the electronic card or board 115 to the microvias 147-148, respectively. The solder members 120-122 are depicted in FIG. 2 as being prior to solder reflow attachment to the metal plating on the microvias 144-146, respectively.

15 FIG. 3 illustrates FIG. 1 after a three-layer redistribution structure has been added to the top surface 48 of the substrate 10 and after a two-layer redistribution structure has been added to the bottom surface 49 of the substrate 10, in accordance with embodiments of the present invention. In particular, FIG. 3 illustrates an electronic structure 200, comprising: the substrate 10, redistribution layer 360 on the top surface 48 of the substrate 10, a redistribution layer 370 on 20 the redistribution layer 360, a redistribution layer 390 on the redistribution layer 370, a redistribution layer 280 on the bottom surface 49 of the substrate 10, and a redistribution layer

290 on the redistribution layer 280. The electronic structure 200 also includes a metal plane 340 (including electrically conductive regions 337) on the redistribution layer 360, a metal plane 380 (including electrically conductive regions 381) on the redistribution layer 370, a metal plane 395 (including electrically conductive regions 396) on the redistribution layer 390, a metal plane 241 (including electrically conductive regions 238) on the redistribution layer 280, and a metal plane 251 (including electrically conductive regions 253) on the redistribution layer 290. Microvias 332-334 go through the redistribution layer 360, microvias 384-385 go through the redistribution layer 370, microvias 344-345 go through the redistribution layer 390, microvias 234-235 go through the redistribution layer 280, and microvias 247-248 go through the redistribution layer 290. Dielectric material of redistribution layer 370 fills the microvias 332-334, dielectric material of redistribution layer 390 fills the microvias 384 and 385, and dielectric material of redistribution layer 290 fills the microvias 234 and 235. The dielectric material of redistribution layers 360, 370, 390, 280, and 290 of FIG. 3 is of the same type as the dielectric material of the redistribution layers 60 and 80 of FIG. 2.

15 The electronic structure 200 further includes an electronic device 310 with attached conductive pads 327 and 328 to which solder members 320-321 (e.g., C4 solder balls) are coupled, respectively. An underfill material (e.g., an organic resin or any underfill material known in the art) 330 encapsulates the solder members 320-321 and fills a space between the electronic device 310 and the redistribution layer 390. The underfill material 330 mitigates 20 adverse effects on the structural integrity of the solder members 320-321 caused (during thermal cycling or other thermal transients) by a mismatch in the CTE between the electronic device 310

and an electronic card or board **215**, and/or between the electronic device **310** and the solder members **320-321**. The solder members **320-321** are also coupled the microvias **344** and **345**, respectively. The electronic structure **200** additionally includes the electronic card or board (e.g., circuit card) **215** with attached conductive pads **216** and **217** to which solder members **224-225** (e.g., BGA solder balls) are coupled, respectively. The solder members **224-225** are also coupled to the microvias **247** and **248**, respectively.

In the electronic structure **200** of FIG. 3, the redistribution layers, metal planes, microvias, and associated electrically conductive couplings and electrically conductive paths have the same or analogous characteristics, properties, features, and advantages, as do the redistribution layers, metal planes, and microvias, and associated electrically conductive couplings and electrically conductive paths in the electronic structure **100** of FIG. 2.

While FIG. 2 depicts a same number (i.e., two) of redistribution layers on the top surface **48** and the bottom surface **49** of the substrate **10**, in general the number of redistribution layers on the top surface **48** and the bottom surface **49** may be different. For example, FIG. 3 shows three redistribution layers (**360**, **370**, and **390**) on the top surface **48**, and two redistribution layers (**260** and **290**) on the bottom surface **49**. Generally, the present invention includes N redistribution layers on (i.e., over) the top surface **48** and P redistribution layers on the bottom surface **49**, wherein at least one of N and P is two or greater, and wherein the other of N and P is zero or a positive integer. The special case of $N = P$ increases symmetry with respect to the ground plane **25** of the substrate **10**, particularly if approximately uniform metal content is symmetrically distributed in the various metal planes with respect to the ground plane **25**. The

aforementioned symmetry of the $N = P$ case has the advantage of making it easier to accommodate thermal stresses that occur during thermal cycling, which reduces or eliminates warping of the substrate **10** and the electronic device **110** of FIG. 2 or **310** of FIG. 3.

FIG. 2 illustrates advantages of the multiple redistribution layers (e.g., the redistribution layers **60**, **70**, **80**, and **90**) on the top surface **48** and on the bottom surface **49** of the substrate **10**. The redistribution layers serve as buildup layers which provides a capability of adding extra wiring layers; e.g., the metal planes **140-141** and **150-151**. The extra wiring level, coupled with the microvias (e.g, the microvias **132-135** and **144-148**) in the multiple redistribution layers, provide extra wireout capability for making more efficient use of space and increasing overall wiring density. In addition, there is increased flexibility in how electrically conductive structure may be distributed inasmuch as a metal plane on each redistribution layer may be any metal distribution, included a signal plane, a power plane, or a ground plane. With the multiple redistribution layers, any metal level on a redistribution layer on the top surface **48** of the substrate **10** may be electrically coupled to any metal level on a redistribution layer on the bottom surface **49** of the substrate **10** or to any internal layer of the substrate **10**, in light of the electrically conductive paths facilitated by the microvias in the redistribution layers **60**, **70**, **80**, and **90** and the PTHs in the substrate **10**. FIG. 2 illustrates several of such electrically conductive paths. For example, the metal plane **140** is electrically coupled to the metal plane **151** through the path of the conductive region **137**, the microvia **133**, the conductive pad **42**, the PTH **32**, the conductive pad **45**, the microvia **135**, and the microvia **148**. As another example, the electronic device **110** is coupled to the conductive pad **44** of the PTH **31** by a path that includes the

conductive pad 128, the solder member 121, the microvia 145, the conductive pad 131, the microvia 132, the conductive pad 41, the PTH 31, and the conductive pad 44. The electronic device 110 may be coupled to wiring in the redistribution layer 70 through the solder member 122 and the microvia 146, or to wiring in the redistribution layer 60 through the solder member 120 and the microvia 144 or through the solder member 121 and the microvias 145 and 132. The number and types of conductive paths facilitated by the multiple redistribution layers of the present invention are virtually unlimited. FIG. 3 also includes the aforementioned features and advantages.

The microvia 144 in FIG. 2 is particularly desirable because it provides an efficient conductive path through more than one redistribution layer. For N redistribution layers on the top surface 48 of the substrate 10, a microvia may go through any M consecutive layers ($1 \leq M \leq N$) starting with the layer that is furthest from the top surface 48.

The multiple redistribution layers of the present invention have an advantage in high frequency applications (i.e., above 1 gigabit such as radio frequency applications) in which it is desirable to maximize the linear dimension of dielectric material between a solder member (i.e., any of the solder members 120-122 or 124-125) and the nearest power plane in the electronic structure 100 of FIG. 2, or between a solder member (i.e., any of the solder members 320-321) and the nearest power plane in the electronic structure 200 of FIG. 3. With use of multiple redistribution layers of dielectric material, said linear dimension in relation to the nearest power plane can be more easily controlled.

If signal planes are formed within a multiple redistribution layer structure, such signal

lines are protected from thermal stresses by the stiff material within the multiple redistribution layers. This enables more signal planes (and thus more wiring levels) to be added while still retaining a low-stress substrate **10** dielectric material such as PTFE which is soft and compliant. As stated *supra*, signal planes within the substrate **10** require protection by power planes in the **10** substrate **10**. Signal planes on redistribution layers, however, do not require protection of such power planes because of the stiffness of the material in the redistribution layers. Thus, the multiple redistribution layers allow improved wireability by allowing addition of signal planes on the redistribution layers, without sacrificing reliability as to thermal stress susceptibility. The multiple redistribution layer structure also makes it feasible to transfer signal planes and/or power planes from the substrate **10** to metal planes of the multiple redistribution layer structure.

As illustrated for the embodiments of FIGS. 2 and 3, the multiple redistribution structure on either the top surface **48** or the bottom surface **49** of the substrate **10** has N dielectric layers (denoted as dielectric layers 1, 2, ..., N), N metal planes (denoted as metal planes 1, 2, ..., N), and a microvia structure, wherein $N \geq 2$. Dielectric layer 1 is on the top surface **48** or the bottom surface **49** of the substrate **10** and thus also on the metal plane **51** or the metal plane **52**, respectively. Metal level 1 is on dielectric layer 1, dielectric layer 2 is on dielectric layer 1 and metal layer 1, metal layer 2 is on dielectric layer 2, ..., dielectric layer N is on dielectric layer $N-1$ and metal layer $N-1$, metal layer N is on dielectric layer N . The microvia structure electrically couples the metal layer N to the metal plane **51** or the metal plane **52** by a collection of microvias coupled with intervening metal levels. The microvia structure includes a microvia or a portion of a microvia through each of the N dielectric layers. Many such combinations of microvias are

possible. An example microvia combination is N microvias (i.e., a microvia in each dielectric layer) such that microvia J is electrically coupled to microvia J-1 by metal plane J-1 for J=2, 3, ..., N. To illustrate, FIG. 3 has N=3 and shows: microvia **345** electrically coupled to microvia **385** by metal plane **380** (specifically, conductive pad **386** in metal plane **380**), microvia **385** 5 electrically coupled to microvia **334** by metal plane **340** (specifically, conductive pad **338** in metal plane **340**), and microvia **334** electrically coupled to metal plane **51** by conductive pad **33**, which electrically couples the metal plane **395** to the metal plane **51** in light of the fact that conductive pad **346** of metal plane **395** is integral with, and thus electrically connected with, the conductive plating of the microvia **346**. Another microvia combination includes a microvia that passes through two or more dielectric layers (e.g., the microvia **144** of FIG. 2). For example and although not shown explicitly in FIG. 3, a microvia could pass through redistribution layers **360**, **370**, and **390**, or through redistribution layers **370** and **390**, just as microvia **144** of FIG. 2 passes through redistribution layers **60** and **70**. Thus in FIG. 3, a microvia passing through redistribution layers **370** and **390** could be electrically coupled by metal plane **340** to a microvia (e.g., the microvia **332**, **333**, or **334**) in redistribution layer **360**.

While embodiments of the present invention have been described herein for purposes of illustration, many modifications and changes will become apparent to those skilled in the art. . Accordingly, the appended claims are intended to encompass all such modifications and changes as fall within the true spirit and scope of this invention.